CHAPTER 6- STRUCTURES INVOLVING SOIL

SECTION 1. SOIL DESCRIPTION

6.1.1 WATERFRONT USE. Earthworks, consisting of soil materials generally enclosed within a protective covering of coarse stone riprap, steel, or concrete skins, are used for waterfront structures, such as dikes, levees, breakwaters, causeways, groins, and seawalls. Soil generally provides the backfill for quaywalls, caissons, and other cellular structures. The most common cause of deterioration and damage to such structures is erosion of the soil by water movements, generally due to wind, tidal, or wave action (References 1-2 and 1-3). Any breaching of or impairment to an earth structure exposed to moving water sharply increases its susceptibility to damage. For this reason it is very critical that any required maintenance be identified and carried out as quickly as possible.

6.1.2 DEFINITION. Soil is composed of particles that differ physically in size and shape and vary in chemical composition. Organic matter, water, air, and bacteria are usually present, but soil consists essentially of mineral matter that has originated from rocks by the action of a series of weathering processes.

6.1.3 SOIL CLASSIFICATION. The complete description of a soil includes: (1) its classification according to the Unified Soil Classification System (see Reference 1-10, Chapter 1, and/or References 6-1, 6-2, or 6-3); (2) its in-situ state, such as structure, density, shear strength, moisture content, etc.; and (3) its mineralogic content. With reference to soils used in waterfront structures it is often sufficient to classify them only according to size (i.e., clay, silt, sand, and gravel). The density, plasticity, and moisture content are most important for the finer-grained soils, while soundness and gradation are most pertinent to the coarser-grained soils and rock fills. The particle size, which marks the boundary between the fine-grained, generally cohesive soils (silts and clays) and the coarse-grained, granular soils (sands and gravels), is approximately the smallest sized particle that is large enough to be individually discernible to the naked eye. This is the minimum size retained on the no. 200 standard sieve (about 0.07 mm in diameter). For the fine-grained materials the Atterberg Limits (ASTM D424 [6-4], D423 [6-5], and D427 [6-6]) are very important as are the moisture contents. Organic soils, such as elastic silts and peats, are never used in the construction or repair of engineering structures, and, therefore, will not be considered herein.

SECTION 2. SOIL PLACEMENT

6.2.1 TYPES OF SOIL. Although most types of inorganic soil materials have been used for waterfront structures, the problems experienced with regard to placement, maintenance, and protection of the fill generally increase markedly as the grain size diminishes. Finer-grained soils in the cohesionless range are extremely susceptible to leaching and erosion, whereas fine-grained cohesive soils are more difficult to compact satisfactorily and may undergo undesirable shrinkage and/or swelling behavior. With granular soils, gradation (i.e., distribution of the various sizes) is important. Uniformly graded soils with a narrow range of particle sizes are difficult to compact, are extremely porous, and obtain lower densities and strengths than soils with a broader distribution of particle sizes. However, where compaction of sands and gravels is involved, the presence of large, oversize cobbles can interfere with the compaction of the finer materials present. Such larger particles can be excluded from the compacted fills and used as riprap or slope protection.

6.2.2 COMPACTION CONTROL. The performance of soil embankments improves with density; thus, soil fill materials should generally be placed at as high a density as is economically feasible, particularly with the finer-grained soils. There is a particular moisture content for a particular soil at which the maximum density is obtained under a specific compaction effort. Thus, moisture control is an important factor toward efficient compaction techniques, particularly with silts, clays, and mixed soils.

The two most common standards for compaction control are the standard Procter (ASTM D-698-58T) [6-7] and the modified Procter (ASTM D-1557-58T) [6-8] tests. The latter method represents a larger compactive effort than the former and has been adopted to account for the higher compactive efforts of current construction equipment. However, the standard considered most pertinent for waterfront structures is still Procter. This is because the lower compactive effort results in a slightly higher optimum moisture content for maximum density, and the higher moisture content is more compatible with the expected in-service conditions of waterfront structures.

A typical requirement for many waterfront structures is to specify a compacted density of 95% of standard Procter, but this may vary with the type of structure and its present condition. It is generally desirable to place a soil material in a structure in as close to its long-term stable condition as possible. Although clean, granular materials should be placed in as saturated a condition as is practicable, fine-grained or mix-grained soils may require moisture contents to be maintained within a particular optimum range. Often, control of water content with respect to the optimum value is left up to the discretion of the contractor, since he can elect to replace rigorous moisture control with increased compactive effort. In cases where excess compactive effort could result in damage to the structure, such as in quaywalls or cofferdams, the compactive effort should be minimized and the moisture content should be controlled as well as is practicable. For these latter types of structures it is also very important that design densities not be exceeded. Excessive compaction might result in undesirable lateral stresses in structural members.

6.2.3 TYPES OF COMPACTION. The type of compaction selected should be based upon the soil type. Vibratory compaction is most efficient with granular soils, whereas kneading types of equipment, such as sheepsfoot rollers, are more applicable to cohesive soils. There is no ready means of controlling the compaction of coarse rock fill. Vibratory rubber-tired compactors in the 12-to-15-ton range are reasonably effective for all types of soil. Soil lift thicknesses should generally be limited to soil layers having a compacted thickness of no more than 6 inches, except in cases where it has been demonstrated that the compactors are capable of achieving the required densities throughout the full depth of thicker lifts. Such a situation might exist with a vibratory compactor on relatively clean, cohesionless material. For backfilling sheet pile cofferdams or other structures of limited extent, it may be necessary to use small hand-operated tampers or compactors. The importance of compaction generally increases with decrease in grain size.

SECTION 3. INSPECTION

Inspection of waterfront soil structures is generally limited to visual observations. In some cases piazometers, survey stations, or other devices may be installed into the structure to facilitate inspection. Unfortunately, the corrosive nature of the waterfront environment inhibits the long-term performance of most permanently installed instrumentation. Pressure-relieved structures, such as some drydocks, are susceptible to destructive uplift pressures due to failure of the dewatering system, development of erosion channels, or deterioration of flow cut-offs, etc. Regular monitoring of pore pressure levels beneath the structure must be carried out and reference made to the design level. In cases where damage is noted or suspected (such as the observance of escaping backfill at the toe of a wall, the presence of sediment in the seepage water, or surface slumping), other techniques, such as drilling exploratory boreholes or using sonic or geophysical techniques, should be resorted to (see Reference 1-10, Chapter 2). A number of sophisticated nondestructive testing techniques, such as those using reflected electromagnetic waves, are occasionally suggested, but the nature of the waterfront, particularly the salty ocean environment, drastically impairs the value of such methods.

SECTION 4. REPAIR

6.4.1 EROSION. The major maintenance requirement for earth-filled waterfront structures consists of preventing the soil from being eroded and replacing the soil when a loss is discovered. This means maintaining sufficient riprap or slope protection on side slopes or insuring the integrity of soil-containing structures, such as sheet pile cofferdams, timber or concrete paneled quaywalls, etc. In cases where there is evidence of

erosion or loss of soil, any protective covering, such as rockfill or armor units, should be removed, and the internal fill material inspected. Any necessary repairs in the form of replacement of properly compacted soil should be made, and the protective slope covering replaced in a manner to insure no further erosion. This may require a series of soil layers of varying coarseness to insure that the finer, central materials cannot be washed out through the coarser, shell materials. In some cases it may be desirable to protect the side slopes of the structure by such means as asphaltic concrete, soil cement, or even reinforced portland cement concrete. In cases where the side slopes are exposed only to atmospheric erosion, vegetation such as ice plant, grasses, etc., might be adequate.

6.4.2 SEALING. The loss of soil from behind quaywalls or from within sheet pile cofferdams, etc., requires sealing of the structure to prevent further loss of material and replacement of suitable backfill. Coarsergrained materials are generally preferred where they are available, since they are less subject to leaching or erosion. Fine-grained materials are desirable only where very low permeability is required, such as in the core of an earth dam. In such cases precautions, such as the construction of inverted filters or sealing of structural joints, etc., are necessary to prevent the erosion of fines. Since surface water (such as rainfall) can contribute greatly to erosion, provision should be made for the disposal of runoff. Where materials consist of the very erodable silts or fine sands, the structure must be sealed to prevent any influx of surface water.

6.4.3 DEWATERING. Where excavation and replacement of soil takes place below the water table, it may be necessary to dewater the site by use of seepage barriers, such as sheet piles. Where soil permeabilities are greater than 1×10^{-3} fpm, subsurface drainage by well points, deep wells, etc., may be necessary (see Reference 1-10, Chapter 8). Prior to planning dewatering procedures it is necessary to determine permeability and piezometric levels by field observations (see Reference 1-10, Chapter 4). The major criterion is to avoid instability through piping or heaving. This is achieved by controlling the upward hydraulic gradient at the base of the excavation. Hydraulic gradients (head loss per unit length of flowpath) of one lead to immediate instability in all cases, but exit gradients of 0.5 to 0.75 will cause unstable working conditions even in clean sands. Silty materials are even more critical.

6.4.4 GROUTING. In some cases it may be more expedient to either seal or repair a damaged structure by injecting grout (see Reference 1-10, Chapter 15, or Reference 6-9). Grout may be used to reduce the permeability of the soil fill or its foundation and, thereby, minimize erosion or leaching. It may also be used to physically strengthen the structure to make it better able to resist wave or ship loadings, superimposed dead loads, etc.

Cavities or voids in the soil structure may be grouted using sand/water mixtures, portland cement, clay, chemical grouts, or a combination of these materials. Sand/water mixtures are applicable only where large cavities are present and the paths of soil loss have been sealed off. Cement grout is not considered applicable if the effective grain size of the in-

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place soils, D_{10} (the sieve size through which only 10% of the soil would pass), is less than 0.5 mm for loose soils and 1.4 mm for dense soils. Thus, portland cement grout is most applicable to the situation where the grout can be pumped directly into cavities.

An effective grouting procedure for sandy materials consists of injecting solutions of sodium silicate and calcium chloride. This procedure both solidifies and impermeabilizes the soil, but it is extremely expensive. Mixtures of cement and clay are also used, sometimes with the addition of a chemical deflocculent. One of the more recently developed chemical grouts polymerizes in the soil voids; however, it is also expensive. With fine-grained backfills, grouting is generally of no benefit except to fill cavities or to seal off paths of soil removal.